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Electrical conductivity mechanism and textures of mineralized sericite schist from the Gold Lake area of the Yellowknife mining district, Northwest Territories¹

S. Connell-Madore and P. Hunt

Connell-Madore, S. and Hunt, P., 2004: Electrical conductivity mechanism and textures of mineralized sericite schist from the Gold Lake area of the Yellowknife mining district, Northwest Territories; Geological Survey of Canada, Current Research 2004-C6, 8 p.

Abstract: The electrical conductivity mechanisms have been determined for five subsamples taken from two mineralized schist samples collected from the Gold Lake area of the Yellowknife mining district, Northwest Territories. The samples were selected to characterize the resistivity of the alteration zone, determine the effect of crosscutting veins, and of fine-grained sulphide minerals oriented parallel to foliation. The purpose of this paper is to document, within the framework of the Yellowknife EXTECH-III Project, results of the laboratory electrical resistivity determinations for use in interpreting ground electromagnetic surveys which have been conducted in the Gold Lake area.

Results indicate that high bulk electrical resistivity (ρ_r) values are likely a result of poor sulphide grain connectivity and of fairly continuous quartz and calcite layers. The lower ρ_r values are due to good sulphide grain connectivity. Alteration visible in hand sample and in scanning electron microscope images suggest that the effect of some pore-fluid conductivity exists as well.

Résumé : On a déterminé les mécanismes de la conductivité électrique pour cinq sous-échantillons provenant de deux échantillons de schiste minéralisé prélevés dans la région du lac Gold, dans le district minier de Yellowknife (Territoires du Nord-Ouest). Les échantillons ont été choisis afin de pouvoir représenter la résistivité de la zone d'altération et de déterminer les effets sur la résistivité de veines discordantes et de sulfures à grain fin orientés parallèlement à la foliation. Le présent article a pour objet de documenter les résultats des déterminations de la résistivité effectuées en laboratoire dans le cadre du projet EXTECH-III de Yellowknife, lesquels serviront à l'interprétation des levés électromagnétiques au sol exécutés dans la région du lac Gold.

Les résultats indiquent que les valeurs élevées de la résistivité électrique apparente (ρ_r) sont vraisemblablement attribuables à une mauvaise connectivité des grains de sulfures et à la présence de couches de quartz et de calcite relativement continues. Les valeurs de ρ_r moins élevées sont attribuables à une bonne connectivité des grains de sulfure. L'altération visible sur les échantillons et sur les microphotographies laisse penser qu'il pourrait en outre exister un certain effet attribuable à la conductivité du fluide interstitiel.

¹ Contribution to the 1999-2003 Yellowknife Mining Camp, Canada-Northwest Territories Exploration Science and Technology (EXTECH III) Initiative.

INTRODUCTION

The electrical conductivity mechanisms have been investigated for two mineralized schist slab samples (Fig. 1) collected from the Gold Lake area of the Yellowknife mining district, Northwest Territories. Three subsamples were cut out from each of these samples to highlight specific features, such as sulphide mineralization, different types of veins (e.g. arsenopyrite, siliceous), and foliation. Two to three specimens were then cut out of five of these six subsamples to further isolate specific features. In total there were 12 specimens investigated. This work consists of analysis and interpretation

of data obtained by 3-D bulk electrical resistivity (ρ_r) measurements (Table 1) and follows similar work previously performed on mineralized and nonmineralized sericitic schist samples from the Giant and Con mine areas (Connell et al., 2000). The samples and specimens were selected to characterize the electrical resistivity of the alteration zone, and determine the effect of crosscutting veins and of fine-grained sulphide minerals oriented parallel to foliation. The purpose of this paper is to document, within the framework of the Yellowknife EXTECH-III Project, results of the laboratory electrical resistivity data for use in interpreting ground electromagnetic surveys which were conducted in the Gold Lake area.

METHOD OF INVESTIGATION

The six subsamples highlighted in this study were cut out from two slab samples, as indicated above, which were selected from a set of four slab samples received from John Kerswill (GSC) who collected them from the Gold Lake area, Northwest Territories. The subsample locations on the slabs were also selected by John Kerswill as indicated in Figure 1, and cut into rectangular shapes. From these subsamples further rectangular specimens were cut and the electrical resistivities (ρ_r) measured in all three directions (Table 1). Methods for these electrical resistivity measurements and anisotropy methods have frequently been described elsewhere (e.g. Scromeda et al., 1993; Katsube and Scromeda, 1994). Some of the surfaces of the specimens were selected, based on their ρ_r values, and polished for scanning electron microscope (SEM) analysis. Generally, specimens with a high anisotropy (λ) value or low ρ_r values were selected for determination of the electrical mechanism of the mineralized schist. The λ is determined by taking the ratio of the highest and lowest ρ_r values that are measured in three directions (Katsube et al., 1997).

A Leica/Cambridge S-360 SEM with Oxford/Link eXL-II energy dispersive X-ray analyzer was used for this analysis. Operating conditions for the SEM were generally 20 kV accelerating voltage at a 25 mm working distance. Backscattered electron images were produced as a result. A detailed description of SEM methods and procedures can be found elsewhere (Reed, 1997).

ANALYTICAL RESULTS AND INTERPRETATION

A schematic presentation of specimen MWA-1BA1 from the sericite schist sample MWA-1 (Fig. 1a) is displayed in Figure 2a. The directions of electrical resistivities (ρ_r) are shown below the block diagram with $74.6 \Omega \cdot m$ and $3360 \Omega \cdot m$ parallel (β -direction) and perpendicular (γ -direction) to foliation, respectively. The electrical anisotropy (λ) for this sample is 45:1. The sulphide grain distribution is evident in the SEM image (Fig. 2b). Good connectivity between the grains are likely the cause of the low ρ_r value in the direction parallel to foliation. Most of the brighter, smaller grains are arsenopyrite and the larger, darker grey grains are pyrite. There are also a few scattered grains which were identified as antimony. This image

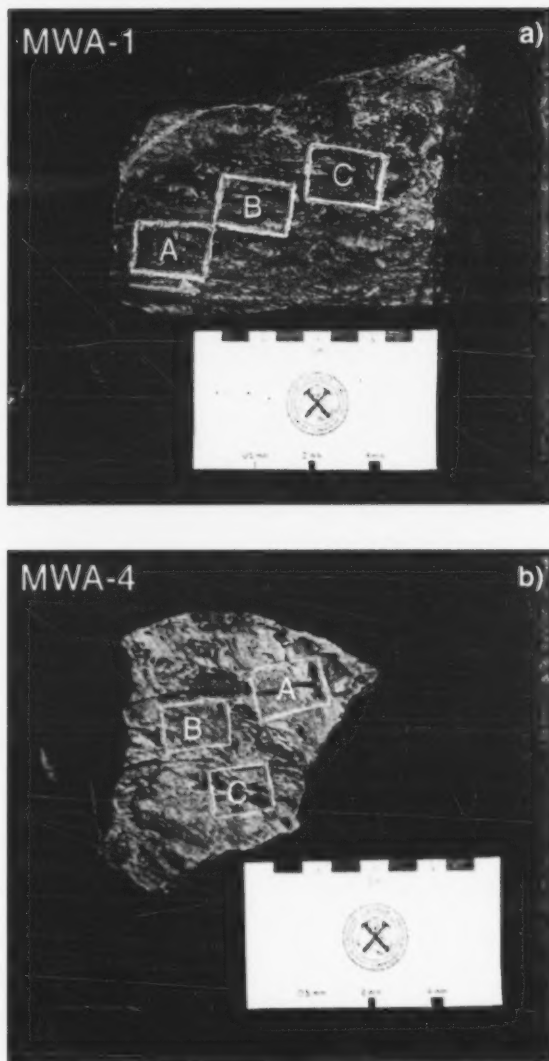


Figure 1. Images of the slabs selected for this study. The locations selected for subsamples are labelled A, B, and C for samples a) MWA-1 and b) MWA-4.

Table 1. Rock descriptions and mean bulk electrical resistivity values for samples collected from the Gold Lake area, Yellowknife, Northwest Territories.

ID/sample number	Subsample number	Specimen number	Special features / comments	Mean ρ , ($\Omega \cdot m$)			Anisotropy (λ)
				α	β	γ	
GL-2-1/ MWA-1	MWA-1A	MWA-1AA	Sericite schist	3245 ± 125	4090 ± 220	—	1.2:1
		MWA-1AB		150.5 ± 0.5	200.5 ± 7.5	—	1.3:1
	MWA-1B	MWA-1BA1		3360 ± 40	74.6 ± 2.7	—	45:1
		MWA-1BB		5950	99.9	—	59.5:1
	MWA-1C	MWA-1C1		1945 ± 65	1255 ± 65	82.7 ± 2	23.5:1
GL-9-4/ MWA-4	MWA-4A	MWA-4AA	Arsenopyrite vein crosscutting dominant foliation	39.75 ± 6.05	5.92 ± 1.36	16.5 ± 0.6	7:1
		MWA-4AB		9.8 ± 2.2	—	—	—
	MWA-4B	MWA-4BA	Siliceous vein parallel to dominant foliation	—	—	—	—
		MWA-4BB		59.4 ± 6.1	—	—	—
		MWA-4BC		—	140.5 ± 16.5	—	—
	MWA-4C	MWA-4CA	Sulphide vein parallel to foliation	30.05 ± 8.75	10.55 ± 0.55	19.65 ± 5.75	3:1
		MWA-4CB		—	23.25 ± 1.55	—	—

ρ , λ = Electrical resistivity and anisotropy values obtained from previously published work (Connell and Scromeda-Perez, 2002).
 α -direction = Direction measured perpendicular to foliation.
 β - and γ -direction = Direction measured parallel to foliation.
 — = No data.

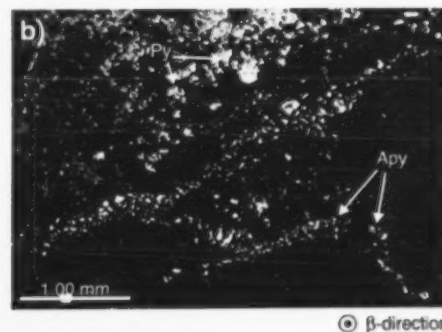
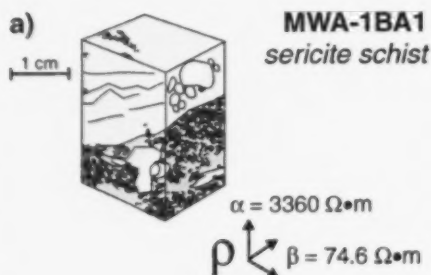


Figure 2. Schematic presentation of a sericite schist subsample MWA-1B represented by a) a block diagram of specimen MWA-1BA1 with sketches of the rock texture and 3-D electrical resistivity (ρ) values shown below. b) A BSE microscope image is displayed for a surface perpendicular to the β -axis showing the distribution of pyrite (Py) and arsenopyrite (Apy).

Table 1. Rock descriptions and mean bulk electrical resistivity values for samples collected from the Gold Lake area, Yellowknife, Northwest Territories.

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		MWA-4AB		9.8 ± 2.2	—	—	—
	MWA-4B	MWA-4BA	Siliceous vein parallel to dominant foliation	—	—	—	—
		MWA-4BB		59.4 ± 6.1	—	—	—
		MWA-4BC		—	140.5 ± 16.5	—	—
	MWA-4C	MWA-4CA	Sulphide vein parallel to foliation	30.05 ± 8.75	10.55 ± 0.55	19.65 ± 5.75	3:1
		MWA-4CB		—	23.25 ± 1.55	—	—

ρ_r, λ = Electrical resistivity and anisotropy values obtained from previously published work (Connell and Scromeda-Perez, 2002).
 α -direction = Direction measured perpendicular to foliation.
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 — = No data.

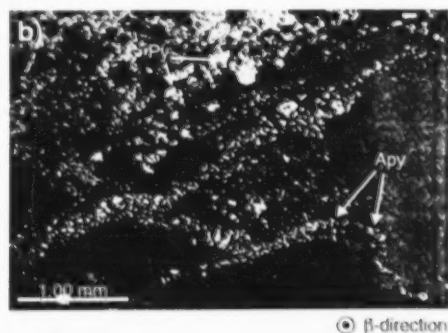
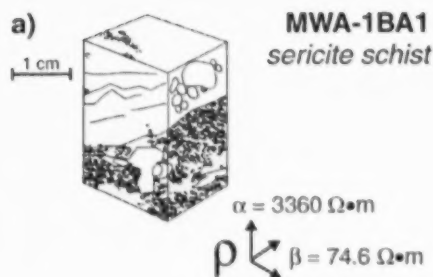


Figure 2. Schematic presentation of a sericite schist subsample MWA-1B represented by **a)** a block diagram of specimen MWA-1BA1 with sketches of the rock texture and 3-D electrical resistivity (ρ_r) values shown below. **b)** A BSE microscope image is displayed for a surface perpendicular to the β -axis showing the distribution of pyrite (Py) and arsenopyrite (Apy).

suggests that the electrical conductivity mechanism of this sample consists of the high sulphide content and the good connectivity of the sulphide minerals in the direction parallel to foliation, and the quartz-rich layers which act as insulators and interrupt the current flow thereby causing the high resistivity in the direction perpendicular to foliation.

A schematic presentation of specimen MWA-1C1 from the sericite schist sample MWA-1 (Fig. 1a) is displayed in Figure 3a. The directions of electrical resistivities (ρ_r) are shown below the block diagram with 82.7–1255 $\Omega\cdot\text{m}$ and 1945 $\Omega\cdot\text{m}$ in the directions parallel and perpendicular to foliation, respectively. The λ value for this subsample is 23.5:1. The mineralogy identified by SEM analysis includes quartz, sericite, pyrite, arsenopyrite, sulphosalts, stibnite, and rutile. Not all minerals identified are shown in the SEM images, however the texture and sulphide grain distribution are shown. Euhedral pyrite grains are shown sparsely distributed with considerably smaller arsenopyrite grains showing weak to moderate preferential alignment parallel to the foliation. The anisotropy in this sample is moderate. The larger ρ_r values in the α - and β -directions result from the quartz-rich layers and poor connectivity of the sulphide grains. The lower ρ_r values are a result of preferential alignment of the platy minerals and arsenopyrite grains. It is likely that there is some connectivity between pore spaces along the sericitic layers, which could

contribute to the increased conductivity, or reduced resistivity in the γ -direction. Representative rocks for the Yellowknife mining district have porosities in the order of 0.2–3.3% (Scromeda-Perez and Connell, 2001; Connell, 2001), but such data have yet to be completed on these samples.

A schematic presentation of specimen MWA-4AA is displayed in Figure 4. The ρ_r values for specimen MWA-4AA are 39.75 $\Omega\cdot\text{m}$ in the direction perpendicular to a mineralized vein and parallel to foliation (α -direction), 5.92 $\Omega\cdot\text{m}$ parallel to the vein and foliation (β -direction) and 16.5 $\Omega\cdot\text{m}$ parallel to the vein and perpendicular to the foliation (γ -direction). The λ value of this specimen is moderate at 7:1. This mineralized vein (arsenopyrite) reduces the ρ_r values considerably. This is likely due to the good interconnectivity between the sulphide grains along the vein (Fig. 4c, d). Since the mineralogy of the host schist consists primarily of quartz and sericite, it is likely that the foliation (connected pores and alignment of platy minerals) is also contributing to the low ρ_r values in the direction parallel to foliation.

The ρ_r value for subsample MWA-4BC (Fig. 5) is 140.5 $\Omega\cdot\text{m}$ in the direction perpendicular to foliation. The ρ_r value is low considering the subsample was cut to isolate a quartz-rich layer. The low ρ_r value suggests a discontinuous siliceous layer and some connectivity of the sulphide minerals across

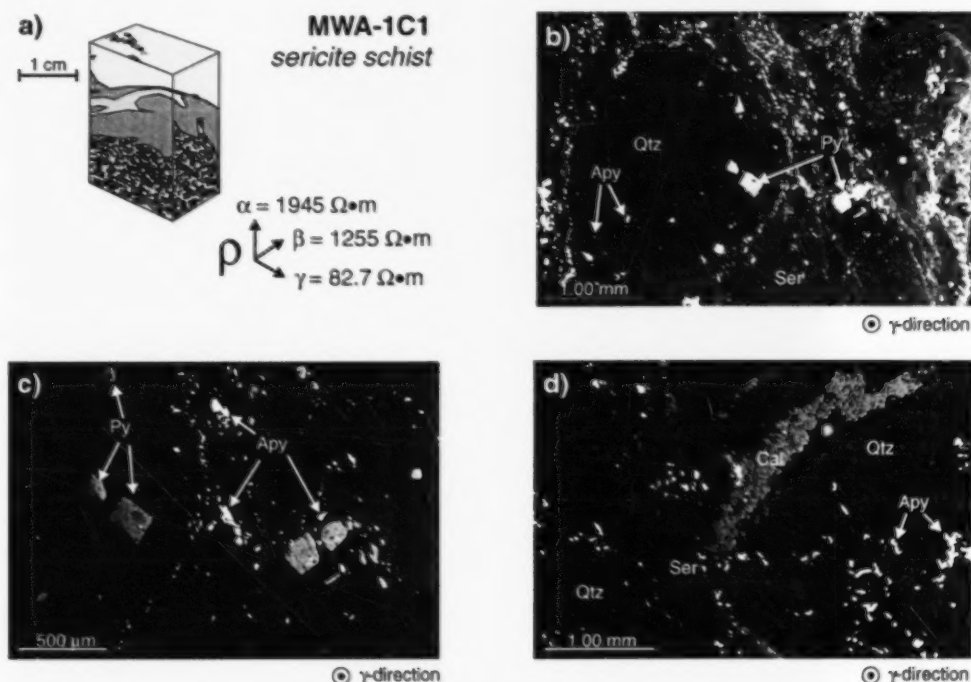


Figure 3. Schematic presentation of a sericite schist subsample MWA-1C1 represented by a) a block diagram of specimen MWA-1C1 with sketches of the rock texture and 3-D ρ_r values shown below. b), c), d) BSE images are displayed for three locations on a surface perpendicular to the γ -direction. Minerals identified include quartz (Qtz), pyrite (Py), arsenopyrite (Apy), sericite (Ser), and calcite (Cal).

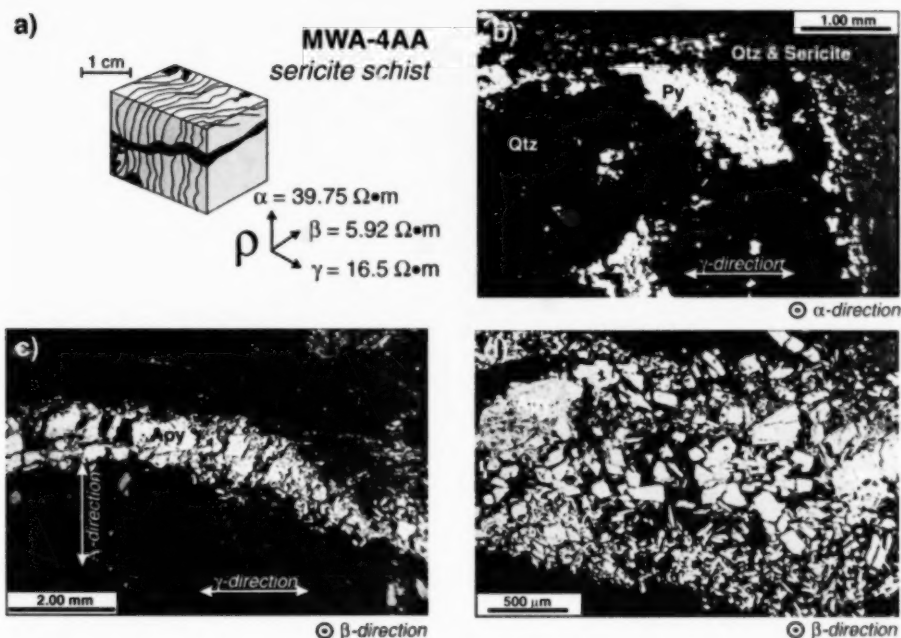


Figure 4. Schematic presentation of a sericite schist subsample MWA-4A represented by a) a block diagram of specimen MWA-4A with sketches of the rock texture and p_r value shown below. Backscatter scanning electron images are displayed for surfaces perpendicular to b) α -direction (top surface of sample sketch), c) and d) and β -direction, with 4d being a close-up of the arsenopyrite (Apy) vein showing good sulphide grain connectivity; Qtz, quartz; Py, pyrite.

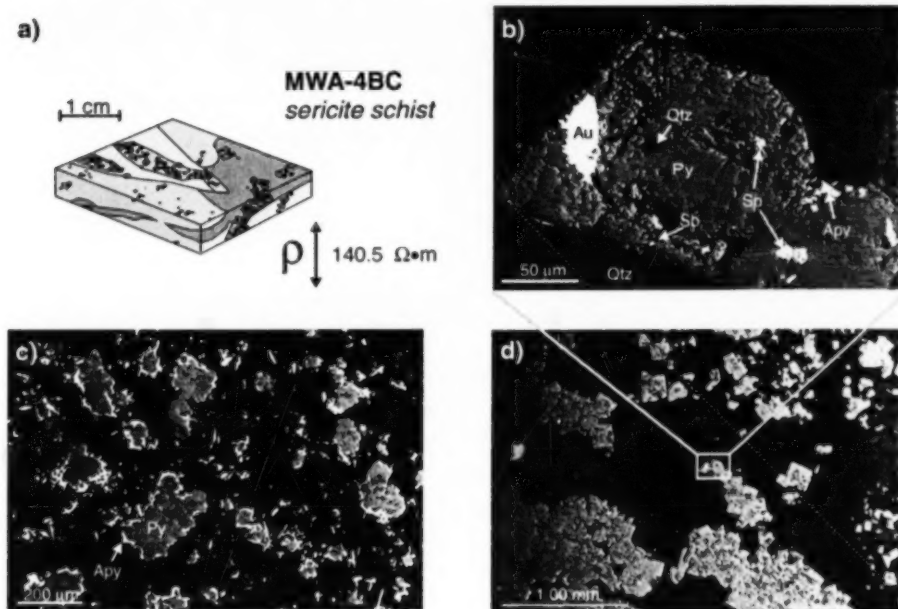


Figure 5. Schematic presentation of a sericite schist subsample MWA-4B represented by a) a block diagram of specimen MWA-4B with sketches of the rock texture and p_r value shown below. Backscatter scanning electron images are displayed for the surface perpendicular to the direction measured. b) An enlarged image of a pyrite (Py) grain with gold (Au), quartz (Qtz), sphalerite (Sp), arsenopyrite (Apy), and stibnite (Sb) inclusions (from image d)). c) Image depicts pyrite grains rimmed by arsenopyrite crystals.

suggests that the electrical conductivity mechanism of this sample consists of the high sulphide content and the good connectivity of the sulphide minerals in the direction parallel to foliation, and the quartz-rich layers which act as insulators and interrupt the current flow thereby causing the high resistivity in the direction perpendicular to foliation.

A schematic presentation of specimen MWA-1C1 from the sericite schist sample MWA-1 (Fig. 1a) is displayed in Figure 3a. The directions of electrical resistivities (ρ_r) are shown below the block diagram with 82.7–1255 $\Omega\cdot\text{m}$ and 1945 $\Omega\cdot\text{m}$ in the directions parallel and perpendicular to foliation, respectively. The λ value for this subsample is 23.5:1. The mineralogy identified by SEM analysis includes quartz, sericite, pyrite, arsenopyrite, sulphosalts, stibnite, and rutile. Not all minerals identified are shown in the SEM images, however the texture and sulphide grain distribution are shown. Euhedral pyrite grains are shown sparsely distributed with considerably smaller arsenopyrite grains showing weak to moderate preferential alignment parallel to the foliation. The anisotropy in this sample is moderate. The larger ρ_r values in the α - and β -directions result from the quartz-rich layers and poor connectivity of the sulphide grains. The lower ρ_r values are a result of preferential alignment of the platy minerals and arsenopyrite grains. It is likely that there is some connectivity between pore spaces along the sericitic layers, which could

contribute to the increased conductivity, or reduced resistivity in the γ -direction. Representative rocks for the Yellowknife mining district have porosities in the order of 0.2–3.3% (Sermeda-Perez and Connell, 2001; Connell, 2001), but such data have yet to be completed on these samples.

A schematic presentation of specimen MWA-4AA is displayed in Figure 4. The ρ_r values for specimen MWA-4AA are 39.75 $\Omega\cdot\text{m}$ in the direction perpendicular to a mineralized vein and parallel to foliation (α -direction), 5.92 $\Omega\cdot\text{m}$ parallel to the vein and foliation (β -direction) and 16.5 $\Omega\cdot\text{m}$ parallel to the vein and perpendicular to the foliation (γ -direction). The λ value of this specimen is moderate at 7:1. This mineralized vein (arsenopyrite) reduces the ρ_r values considerably. This is likely due to the good interconnectivity between the sulphide grains along the vein (Fig. 4c, d). Since the mineralogy of the host schist consists primarily of quartz and sericite, it is likely that the foliation (connected pores and alignment of platy minerals) is also contributing to the low ρ_r values in the direction parallel to foliation.

The ρ_r value for subsample MWA-4BC (Fig. 5) is 140.5 $\Omega\cdot\text{m}$ in the direction perpendicular to foliation. The ρ_r value is low considering the subsample was cut to isolate a quartz-rich layer. The low ρ_r value suggests a discontinuous siliceous layer and some connectivity of the sulphide minerals across

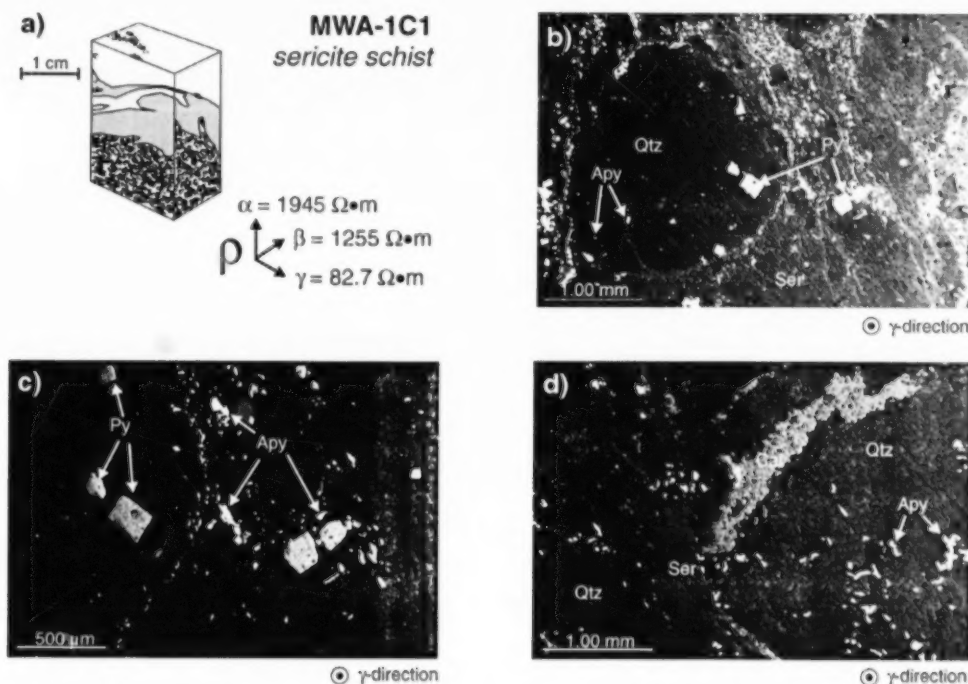


Figure 3. Schematic presentation of a sericite schist subsample MWA-1C represented by a) a block diagram of specimen MWA-1C1 with sketches of the rock texture and 3-D ρ_r values shown below. b), c), d) BSE images are displayed for three locations on a surface perpendicular to the γ -direction. Minerals identified include quartz (Qtz), pyrite (Py), arsenopyrite (Apy), sericite (Ser), and calcite (Cal).

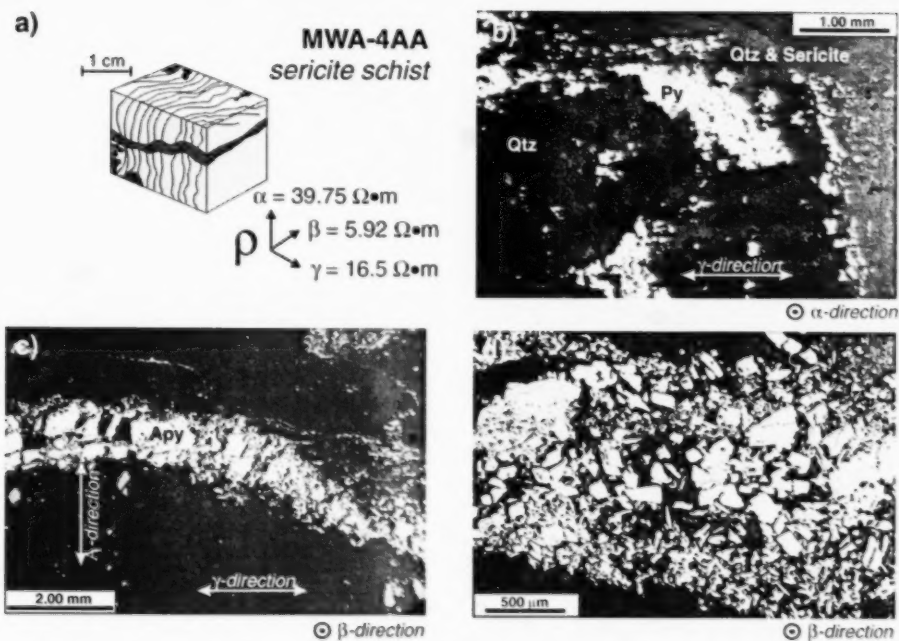


Figure 4. Schematic presentation of a sericite schist subsample MWA-4A represented by a) a block diagram of specimen MWA-4A with sketches of the rock texture and ρ_r value shown below. Backscatter scanning electron images are displayed for surfaces perpendicular to b) α -direction (top surface of sample sketch), c) and d) and β -direction, with d) being a close-up of the arsenopyrite (Apy) vein showing good sulphide grain connectivity: Qtz, quartz; Py, pyrite.

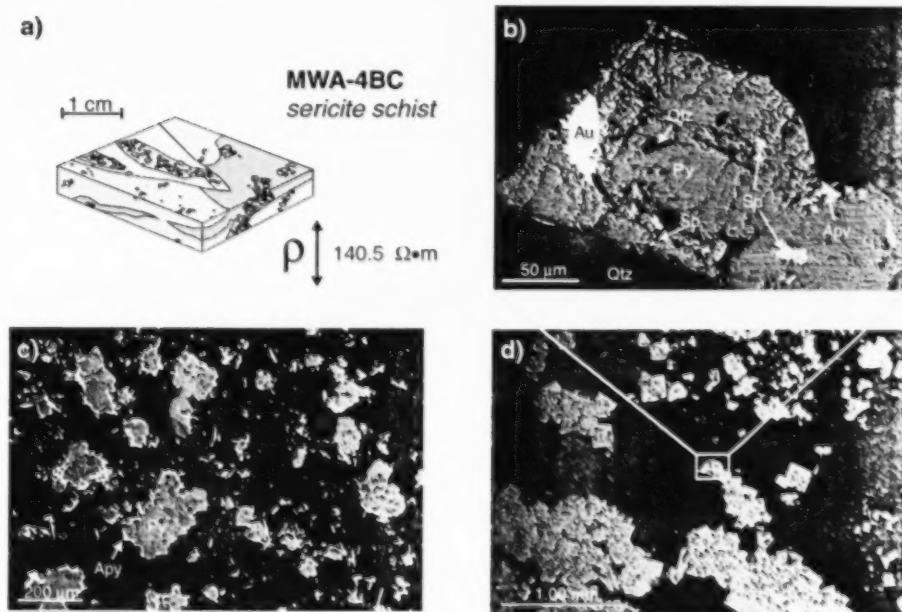


Figure 5. Schematic presentation of a sericite schist subsample MWA-4B represented by a) a block diagram of specimen MWA-4BC with sketches of the rock texture and ρ_r value shown below. Backscatter scanning electron images are displayed for the surface perpendicular to the direction measured. b) An enlarged image of a pyrite (Py) grain with gold (Au), quartz (Qtz), sphalerite (Sp), arsenopyrite (Apy), and stibnite (Sb) inclusions (from image d)). c) Image depicts pyrite grains rimmed by arsenopyrite crystals.

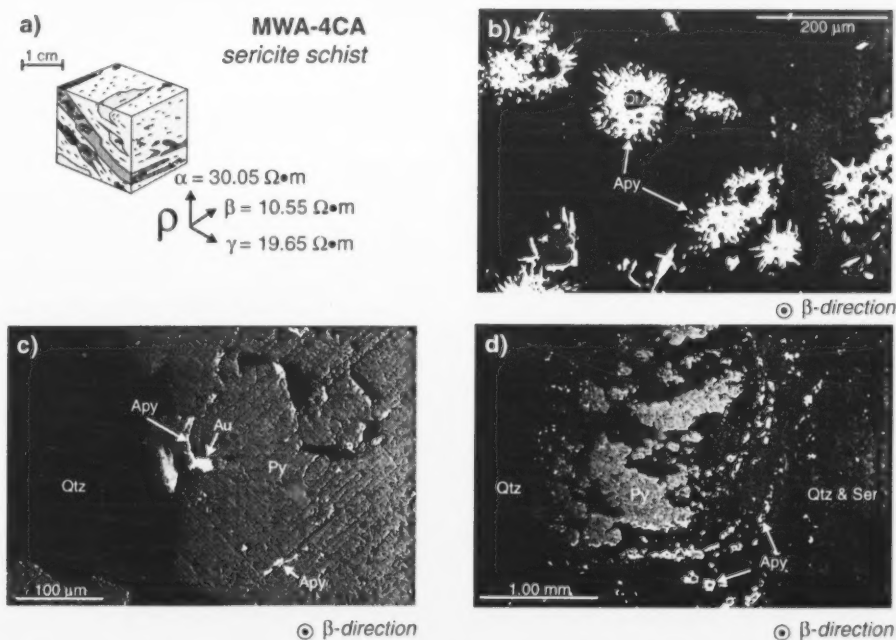


Figure 6. Schematic presentation of sericite schist subsample MWA-4C represented by a) a block diagram of specimen MWA-4CA with sketches of the rock texture and 3-D ρ_r values shown below. Backscatter scanning electron images are displayed for the surface perpendicular to the β -direction. Images show b) quartz (Qtz) grains rimmed by arsenopyrite (Apy). c) a close-up of a pyrite (Py) grain with a gold (Au) inclusion, and d) the distribution of grains rimmed by arsenopyrite with relation to the larger pyrite grains. Sericite (Ser) is also identified.

the layer. Mineralogy identified in this subsample includes quartz, sericite, carbonate, arsenopyrite, pyrite, sphalerite, and trace galena and gold. A pyrite grain in the SEM image (Fig. 5b) shows the inclusions of other minerals. The SEM image, Figure 4c, shows fine-grained arsenopyrite crystals in the groundmass and rimming some of the pyrite grains.

The ρ_r values for specimen MWA-4CA (Fig. 6) are all low with $30.05 \Omega \cdot m$ in the direction perpendicular to foliation (α -direction) and 10.55 – $19.65 \Omega \cdot m$ in the directions parallel to foliation (β - and γ -directions). Sericite, quartz, pyrite, arsenopyrite, galena, sphalerite and gold were all identified under the SEM. Arsenopyrite crystals rim some of the pyrite and quartz grains as seen in Figures 6b and 6d. This specimen was selected to isolate a sulphide-rich zone. The ρ_r values indicate good connectivity between the sulphide grains. The λ is low (3:1) suggesting that the effect of foliation is small. The electrical mechanism of this sample is likely the good connectivity between the sulphide grains and the good pore-fluid connection in all three directions. Effective porosity measurements specifically on this sample would provide more information.

DISCUSSION AND CONCLUSIONS

All of the samples and specimens used in this study were obtained from the Gold Lake area, N.W.T. One of these specimens has isolated an arsenopyrite vein (MWA-4AA; Fig. 4) with the bulk electrical resistivity (ρ_r) value of $40 \Omega \cdot m$ in the direction perpendicular to it, and 6 – $16.5 \Omega \cdot m$ in the direction parallel to the vein. This vein, which is an arsenopyrite-filled fracture, shows the lowest ρ_r values in this study. Good connectivity between grains is visible in SEM images (Fig. 4c, d). In another study (Jones et al., 1997), an example is shown of highly concentrated sulphide minerals accumulated at the hinge of a fold, which results in low ρ_r values (3 – $8 \Omega \cdot m$) being displayed in only one direction.

The anisotropy (λ) values of these specimens are in the range of 3:1 to 7:1. Generally, the ρ_r range for these specimens is low, probably due to the high sulphide content and good to moderate connectivity between sulphide grains (Connell and Scromeda-Perez, 2002).

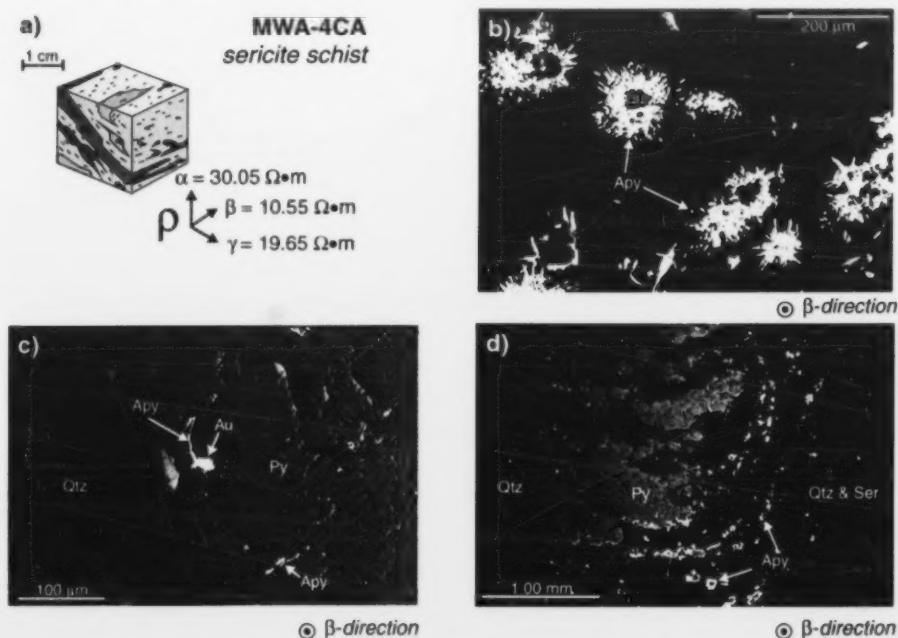


Figure 6. Schematic presentation of sericite schist subsample MWA-4C represented by **a)** a block diagram of specimen MWA-4CA with sketches of the rock texture and 3-D ρ_r values shown below. Backscatter scanning electron images are displayed for the surface perpendicular to the β -direction. Images show **b)** quartz (Qtz) grains rimmed by arsenopyrite (Apy). **c)** a close-up of a pyrite (Py) grain with a gold (Au) inclusion, and **d)** the distribution of grains rimmed by arsenopyrite with relation to the larger pyrite grains. Sericite (Ser) is also identified.

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The ρ_r values for specimen MWA-4CA (Fig. 6) are all low with $30.05 \Omega \cdot \text{m}$ in the direction perpendicular to foliation (α -direction) and 10.55 – $19.65 \Omega \cdot \text{m}$ in the directions parallel to foliation (β - and γ -directions). Sericite, quartz, pyrite, arsenopyrite, galena, sphalerite and gold were all identified under the SEM. Arsenopyrite crystals rim some of the pyrite and quartz grains as seen in Figures 6b and 6d. This specimen was selected to isolate a sulphide-rich zone. The ρ_r values indicate good connectivity between the sulphide grains. The λ is low (3:1) suggesting that the effect of foliation is small. The electrical mechanism of this sample is likely the good connectivity between the sulphide grains and the good pore-fluid connection in all three directions. Effective porosity measurements specifically on this sample would provide more information.

DISCUSSION AND CONCLUSIONS

All of the samples and specimens used in this study were obtained from the Gold Lake area, N.W.T. One of these specimens has isolated an arsenopyrite vein (MWA-4AA; Fig. 4) with the bulk electrical resistivity (ρ_r) value of $40 \Omega \cdot \text{m}$ in the direction perpendicular to it, and 6 – $16.5 \Omega \cdot \text{m}$ in the direction parallel to the vein. This vein, which is an arsenopyrite-filled fracture, shows the lowest ρ_r values in this study. Good connectivity between grains is visible in SEM images (Fig. 4c, d). In another study (Jones et al., 1997), an example is shown of highly concentrated sulphide minerals accumulated at the hinge of a fold, which results in low ρ_r values (3 – $8 \Omega \cdot \text{m}$) being displayed in only one direction.

The anisotropy (λ) values of these specimens are in the range of 3:1 to 7:1. Generally, the ρ_r range for these specimens is low, probably due to the high sulphide content and good to moderate connectivity between sulphide grains (Connell and Scromeda-Perez, 2002).

The ρ_r values for all of the Gold Lake samples measured to date, are in the range of 5.92–5950 $\Omega\cdot\text{m}$ (e.g. Connell and Scromeda-Perez, 2002). The higher ρ_r values are more likely a result of poor connectivity of sulphide grains, although a few of the samples have lower concentrations of the conductive minerals (e.g. Connell and Scromeda-Perez, 2002). The highest λ value (59.5:1) in this study is for sericite schist specimen MWA-1BB. This specimen is moderate to strongly foliated with the lowest ρ_r measured in the direction parallel to foliation (β -direction; 99.9 $\Omega\cdot\text{m}$) and is likely a result of good connections between the sulphide grains. The higher ρ_r value (5950 $\Omega\cdot\text{m}$) of that specimen is in the direction perpendicular to foliation and is likely a result of fairly continuous quartz and calcite layers. Alteration, which is visible in the hand sample and in the SEM images, suggests that some effect of pore-fluid conductivity is likely present as well. This could be confirmed by porosity measurements.

Overall, the electrical mechanisms for these two slab samples can be described as being influenced by the connectivity of sulphide grains, continuous quartz and calcite layers, and possible pore-fluid connection. These two sericite schists have ρ_r values in the ranges of 150–5950 $\Omega\cdot\text{m}$ and 10–60 $\Omega\cdot\text{m}$ perpendicular to foliation and 75–4090 $\Omega\cdot\text{m}$ and 6–140 $\Omega\cdot\text{m}$ parallel to foliation, for samples MWA-1 and MWA-4, respectively. The higher values fall into the range of other sericite schist samples measured from the Giant and Con mines (1560–7510 $\Omega\cdot\text{m}$ perpendicular to foliation and 360–5380 $\Omega\cdot\text{m}$ parallel to foliation; Connell et al. (2000)). The samples presented in this study generally have lower ρ_r values as a result of their higher sulphide content.

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